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EFFECT OF OVERSTRAIN IN AUTOFRETTAGE UPON MECHANICAL PROPERTIES OF GUN TUBES

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A study was undertaken to determine the effect of excessive and normal overstrain on mechanical properties in gun tubes.

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INTRODUCTION

The autofrettage process induces compressive residual stresses at the bore of a gun tube which improve the capability of the tube to overcome firing stresses. At Watervliet Arsenal, the swage autofrettage process consists of pushing an oversized mandrel through the lubricated bore of the gun tube. Unpublished test data from a preliminary study[1] by Dr. Vito Colangelo at the Watervliet Arsenal (Table I) revealed that certain mechanical properties, notably impact energy, were adversely affected by overstrain in autofrettage.

Examination of some early process data on the 152mm M81 gun tube indicated that a slight drop in impact energy and an increase in yield strength occurred as a result of autofrettage. The results were not conclusive, however. If such variations in mechanical properties were significant, the information could be factored into the material requirements for weapons in production and in the design stage. This study was undertaken to determine the effect of excessive and normal overstrain upon mechanical properties in gun tubes.

Test Procedure

A test program was devised to obtain a direct correlation between overstrain and mechanical properties by varying the amount of overstrain in gun tube material, and then sectioning the material for test purposes.

The procedure consisted of machining two 105mm M68 rough forgings to the dimensions of the breech and muzzle ends of a gun tube prior to the swage autofrettage process. The tubes were then cut into nine two-foot long cylinders which produced three cylinders of the breech dimension and six cylinders of the muzzle dimension for each forging. The specimen configuration is shown in Figure 1 and produced a breech wall ratio of 2.20 and a muzzle wall ratio of 1.55. These specimens were heat treated in-house to assure uniformity of material, and then machined to the swage detail.

The heat treat cycle consisted of austenitizing at 1550°F for two hours on the muzzle specimens, four hours on the breech specimens. They were quenched vertically into water, timed for 45 seconds on the smaller wall, three minutes on the larger wall. Further cooling was continued in oil until the temperature of the pieces dropped below 212°F. Tempering was then conducted at 1025°F for three hours.

The swage procedure consisted of swaging the specimen with an oversized mandrel (4.258" diameter), grinding the mandrel down for the next swage cycle and continuing to swage to obtain varying degrees of overstrain as shown in Table II.

In order to develop a more comprehensive picture, a number of specimens were thermal soaked at 675°F for five hours after overstrain and tensile test specimens were made to compare with non-thermal soaked specimens. Results of this comparison are shown in Table III.

A microstructural examination was also made to determine whether overstrain resulted in any visible changes in material structure. These photomicrographs appear in Figure 2 and Figure 3 for the specimen (1582 MEY4) which experienced the greatest amount of overstrain.

Charpy V-notch specimens were taken before autofrettage from two cylinders (1582 ME3 and 1585 BE19), and tested at temperatures from -150°F to + 120°F to serve as a basis for comparison with the post-autofrettage impact data. The comparative data is shown for 1585 in Figure 4 and for 1582 in Figure 5.

DISCUSSION AND RESULTS

Comparative values before and after overstrain are shown in Table II for tensile strength, yield strength, reduction in area, elongation, and impact energy.

Effect of Overstrain on Mechanical Properties

The test results summarized in Table II and Figs. 4 & 5 indicate that the yield strength generally increases and Charpy (room temperature) impact values generally decrease with overstrain. However, the changes are small, averaging about 5% for the yield strength. The cylinder with the largest amount of overstrain (Specimen #1) increased 4.05% in yield strength and decreased 12.6% in impact energy. The cylinder with the smallest amount of overstrain (#12) increased 6.4% in yield strength and decreased 4.1% in impact energy. Yield strength results are presented graphically in Figure 6.

An attempt to statistically correlate the change in yield strength and impact energy after autofrettage with the degree of overstrain proved unsuccessful.

Effect of Thermal Treatment Upon Tensile Properties

A series of selected test specimens were thermally treated after overstrain and the test results are shown in Table III. In this table test values before autofrettage, after autofrettage and subsequent to autofrettage, plus thermal treatment are displayed.

It is clearly evident from Table III and Figure 6 that the thermal treatment after autofrettage increases the yield strength. It is also evident that the yield strength is increased by the autofrettage process. This increase in yield strength after autofrettage and thermal relief is substantially in agreement with the work of G. Sachs (4) who determined that the effect of stress relief was to increase the yield strength about 7% in the circumferential direction.

The results we obtained indicated that autofrettage followed by thermal stress relief increased the yield strength a minimum of 8.1% increasing with overstrain to a maximum of 14.4%.

The increase in yield strength after thermal treatment subsequent to autofrettage is most likely due to two factors: the removal of Bauschinger effects resulting from the swage operation and possible strain aging effects. Strain aging results when the carbon atoms pin mobile dislocations in a strained specimen. This immobilization might take many days at room temperature, but occurs quite readily at increased temperatures. The net effect is an increase in yield strength above the initially obtained value. With regard to studies of the Bauschinger effect, specimens extracted from stressed cylinders do not present an ideal case for analysis since the stress state is exceedingly complex, being composed of longitudinal, radial and circumferential stresses which are difficult to quantify. Uniaxial specimens, such as those used by Milligan et al[5], are much more conducive to accurate analysis, and, therefore, the contribution due to Bauschinger effects may be determined more precisely.

Effect of Overstrain Upon Grain Structure

Photomicrographs of the grain structure before and after overstrain taken at the same radial location are shown in Figures 2 and 3. It is evident from the microstructure that the steel is tempered martensite and that the overstrain in this range (Specimen #1) produces no evidence of plastic deformation or grain reorientation.

Effect of Autofrettage on Impact Strength at Various Test Temperatures

Examination of the curves for impact strength at various temperatures for Tubes 1585 and 1582 (Figures 4 and 5) reveals that there is a general decrease in impact strength as the test temperature decreases. The magnitude of the decrease varied from specimen to specimen and showed little correlation with the degree of overstrain (Table II).

CONCLUSIONS

1. It is apparent from these test results that overstrain in swage autofrettage beyond the 100% level has only a small effect upon the mechanical properties of a gun tube. The increase in yield strength of 4.0% in specimen #1 does not appear significant at the level of overstrain. It is evident, however, that autofrettage does increase yield strength and that the change is relatively independent of the initial yield strength.

2. There is a decrease in impact energy as a result of the autofrettage process, the change being slightly greater at -40°F than at room temperature. The decrease in impact energy appears to increase with increasing overstrain in specimens from tubes of both wall ratios

3. Microstructural examination of the specimens reveal no visible evidence of cold work as a result of the swage autofrettage process since the photomicrographs at maximum overstrain show no grain orientation.

4. The thermal treatment after overstrain clearly increased the yield strength of the test cylinders. Our tests indicated autofrettage plus thermal treatment increased yield from 8.2 to 14.4%. The effect of thermal treatment after autofrettage on Charpy impact energy values was not included in this study.

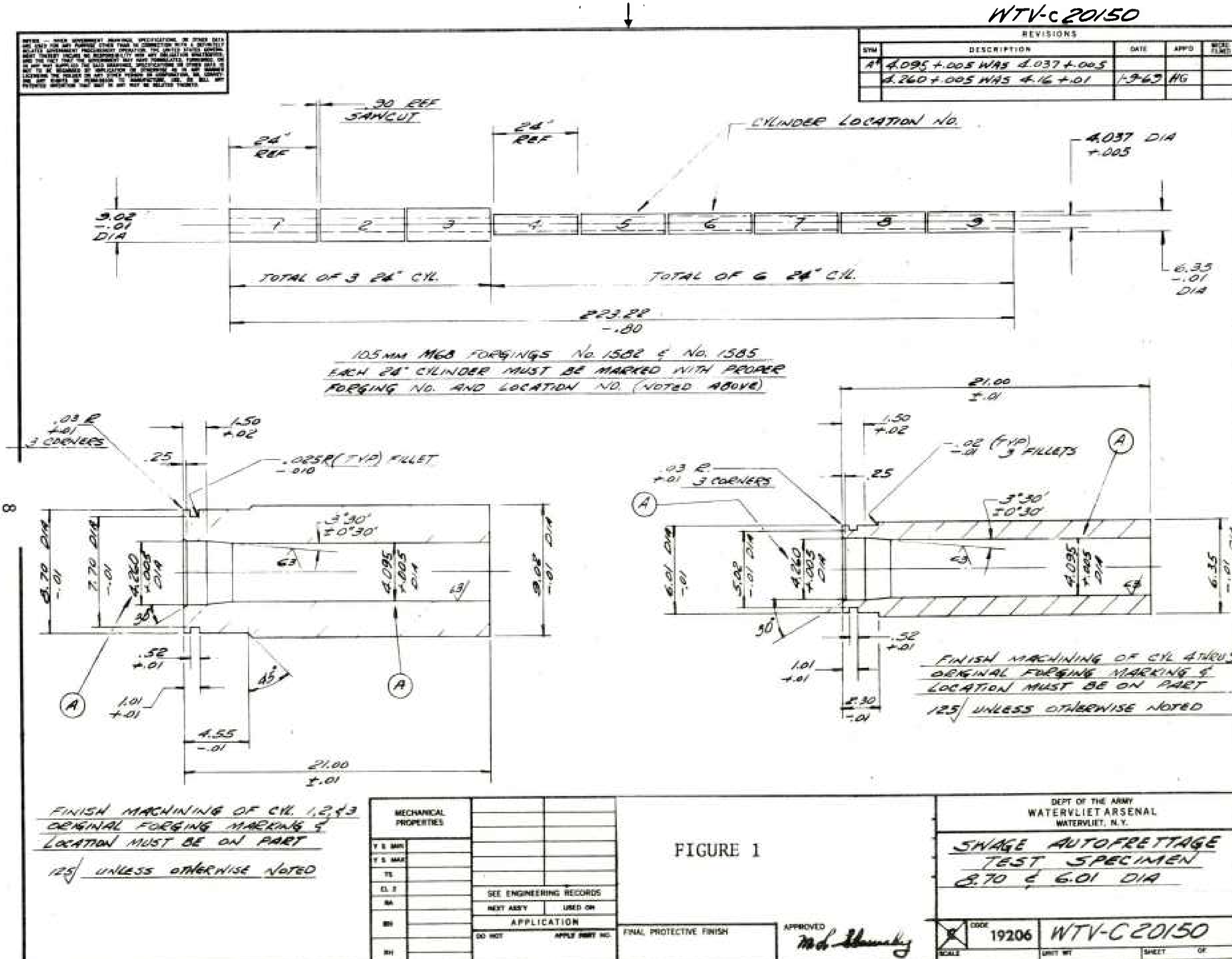
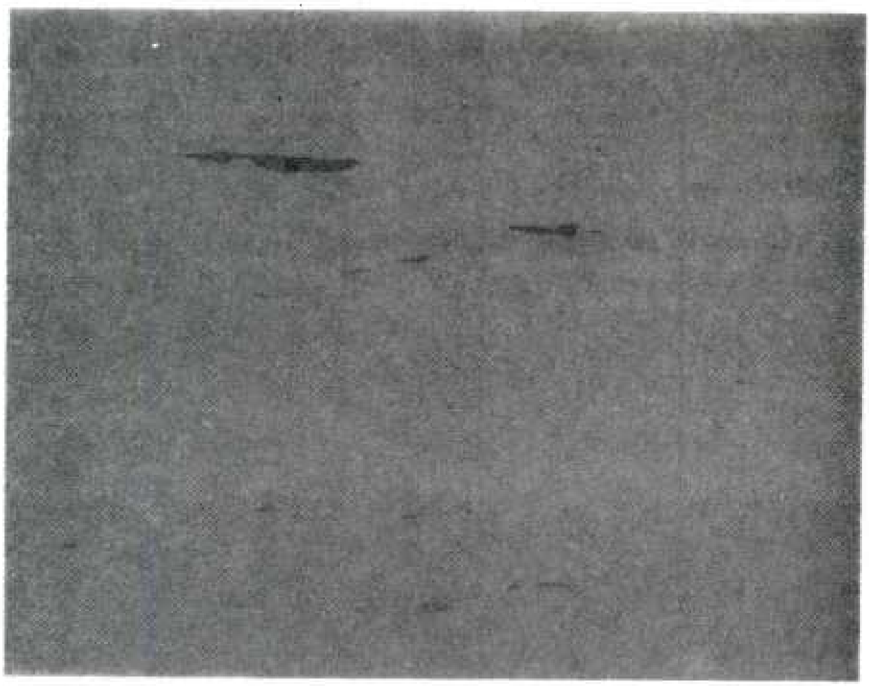

WTV-C20150
REVISIONS
SYM | DESCRIPTION | DATE | APP'D
A | 4.095 +.005 WAS 4.037 +.005
4.260 +.005 WAS 4.16 +.01 | 1-9-63 | HG
.30 REF SAWCUT
24" REF
24" REF
CYLINDER LOCATION NO.
4.037 DIA +.005
9.02 -.01 DIA
1 2 3 4 5 6 7 8 9
TOTAL OF 3 24" CYL.
TOTAL OF 6 24" CYL.
6.35 -.01 DIA
223.22 -.80
105MM M68 FORGINGS No. 1582 & No. 1585
EACH 24" CYLINDER MUST BE MARKED WITH PROPER FORGING No. AND LOCATION NO. (NOTED ABOVE)
.03 R +.01 3 CORNERS
.25
1.50 +.02
.025R (TYP) FILLET -.010
3°30' ±0°30'
8.70 -.01 DIA
7.70 DIA -.01
4.260 +.005 DIA
4.095 +.005 DIA
9.02 -.01 DIA
30°
45°
.52 +.01
1.01 +.01
4.55 -.01
21.00 ±.01
FINISH MACHINING OF CYL. 1,2 & 3
ORIGINAL FORGING MARKING & LOCATION MUST BE ON PART
125 UNLESS OTHERWISE NOTED
21.00 ±.01
1.50 +.02
.02 (TYP) -.01 3 FILLETS
.03 R +.01 3 CORNERS
.25
3°30' ±0°30'
6.01 DIA -.01
5.02 -.01 DIA
4.260 +.005 DIA
4.095 +.005 DIA
6.35 -.01 DIA
30°
.52 +.01
1.01 +.01
2.30 -.01
FINISH MACHINING OF CYL 4 THRU 9
ORIGINAL FORGING MARKING & LOCATION MUST BE ON PART
125 UNLESS OTHERWISE NOTED
MECHANICAL PROPERTIES
Y S MIN
Y S MAX
TS
EL %
RA
BH
SEE ENGINEERING RECORDS
NEXT ASSY
USED ON
APPLICATION
DO NOT
APPLY PART NO.
FINAL PROTECTIVE FINISH
APPROVED
DEPT OF THE ARMY
WATERVLIET ARSENAL
WATERVLIET, N.Y.
SWAGE AUTOFRETTAGE TEST SPECIMEN
8.70 & 6.01 DIA
CODE 19206
WTV-C20150
SCALE
UNIT WT
SHEET
OF

FIGURE 1

BEFORE AUTOFRETTAGE

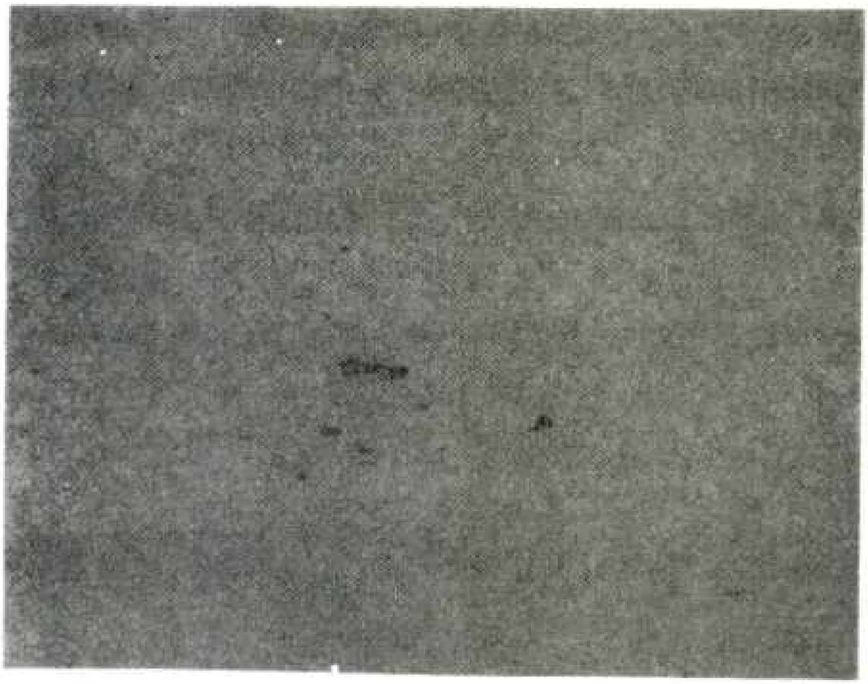


4% Picral & HCl etch 100X

4% Picral & HCl etch 1000X

FIGURE 2

AFTER AUTOFRETTAGE



4% Picral & HCl Etch 100X

4% Picral & HCl Etch 1000X

FIGURE 3

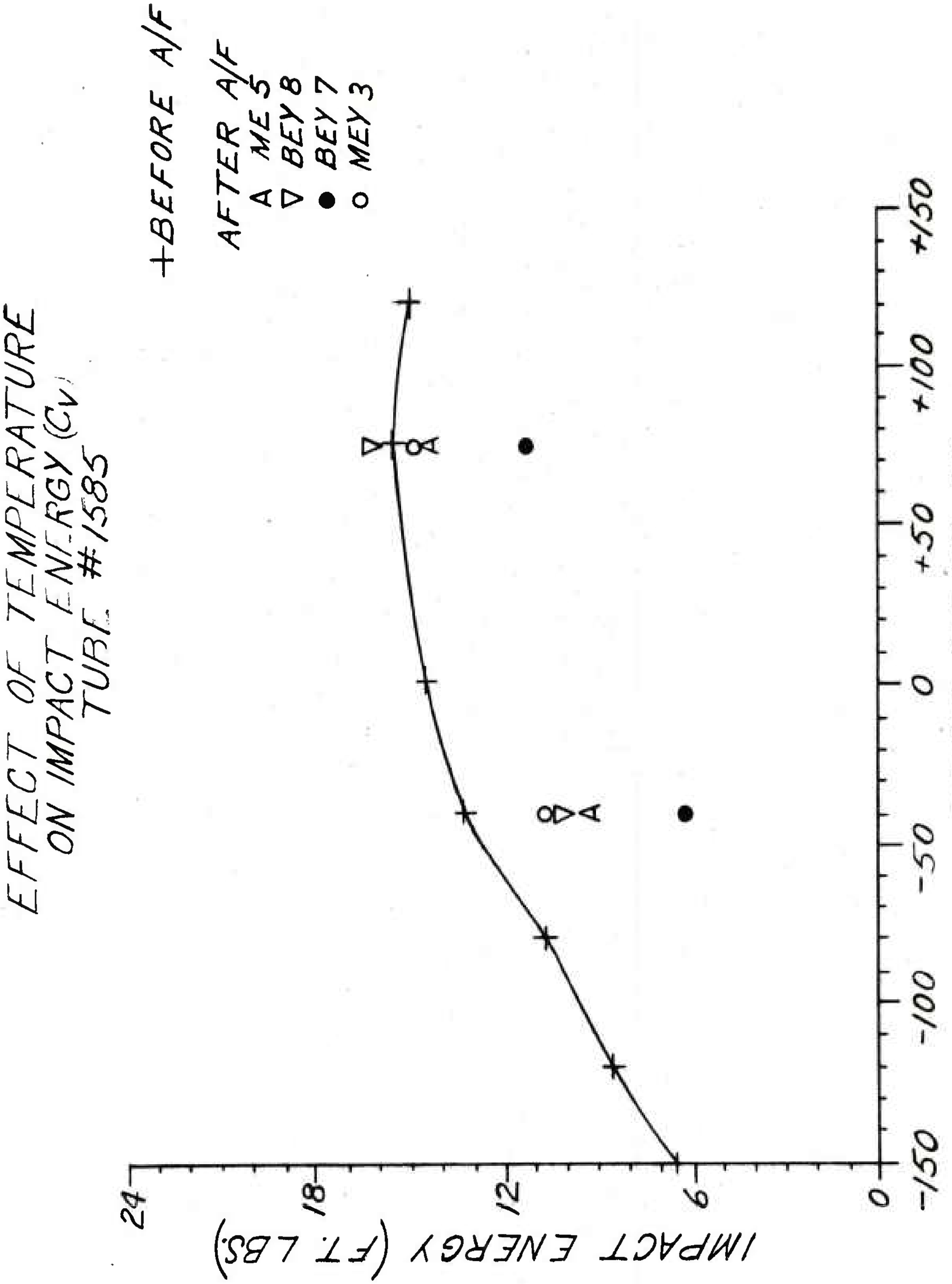

EFFECT OF TEMPERATURE
ON IMPACT ENERGY (Cv)
TUBE #1585
+BEFORE A/F
AFTER A/F
A ME 5
▽ BEY 8
● BEY 7
○ MEY 3
IMPACT ENERGY (FT. LBS.)
24
18
12
6
0
-150
-100
-50
0
+50
+100
+150
TEST TEMP °F

FIG. 4

EFFECT OF TEMPERATURE ON IMPACT ENERGY (C_V) TUBE #1582

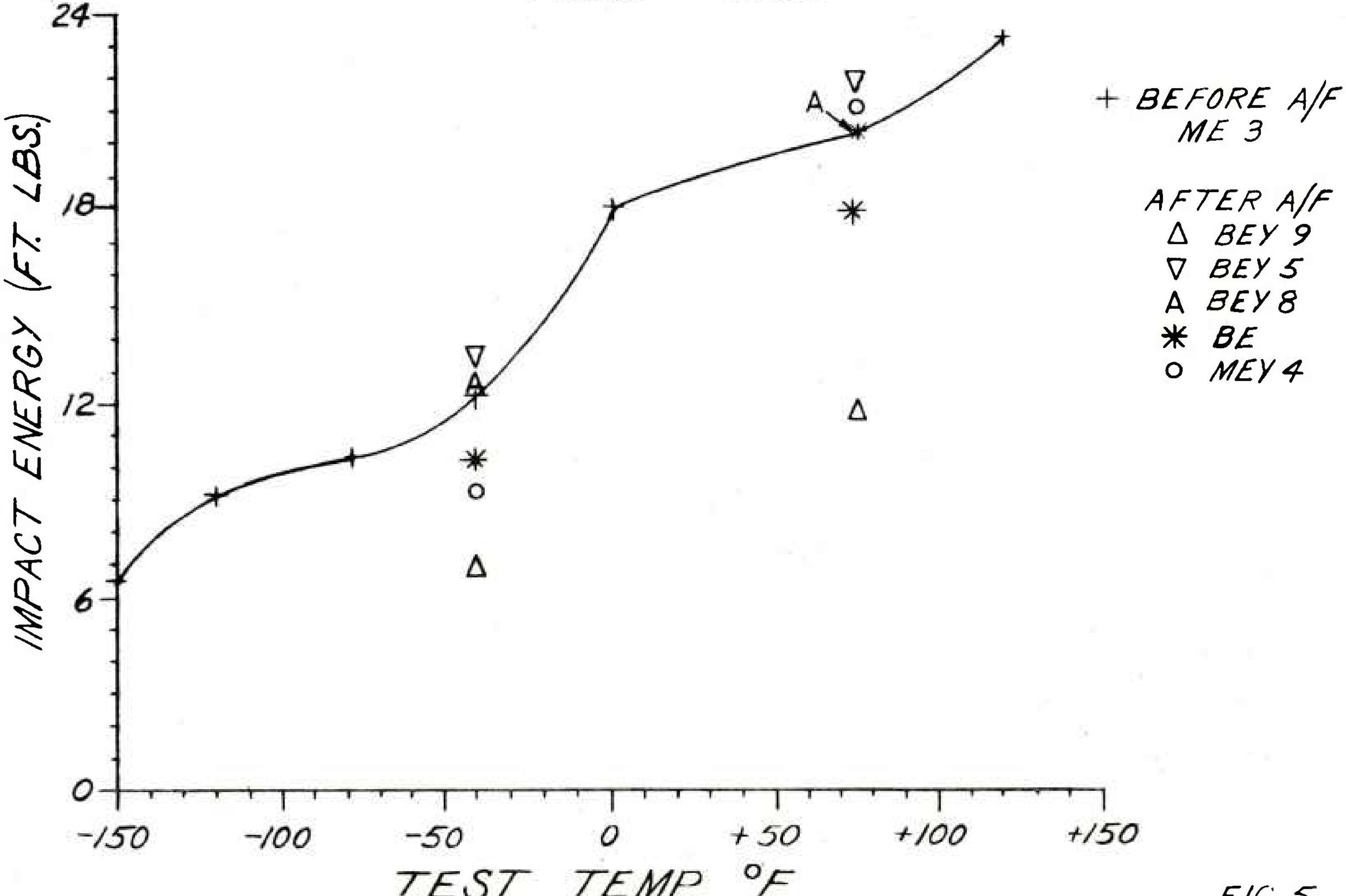
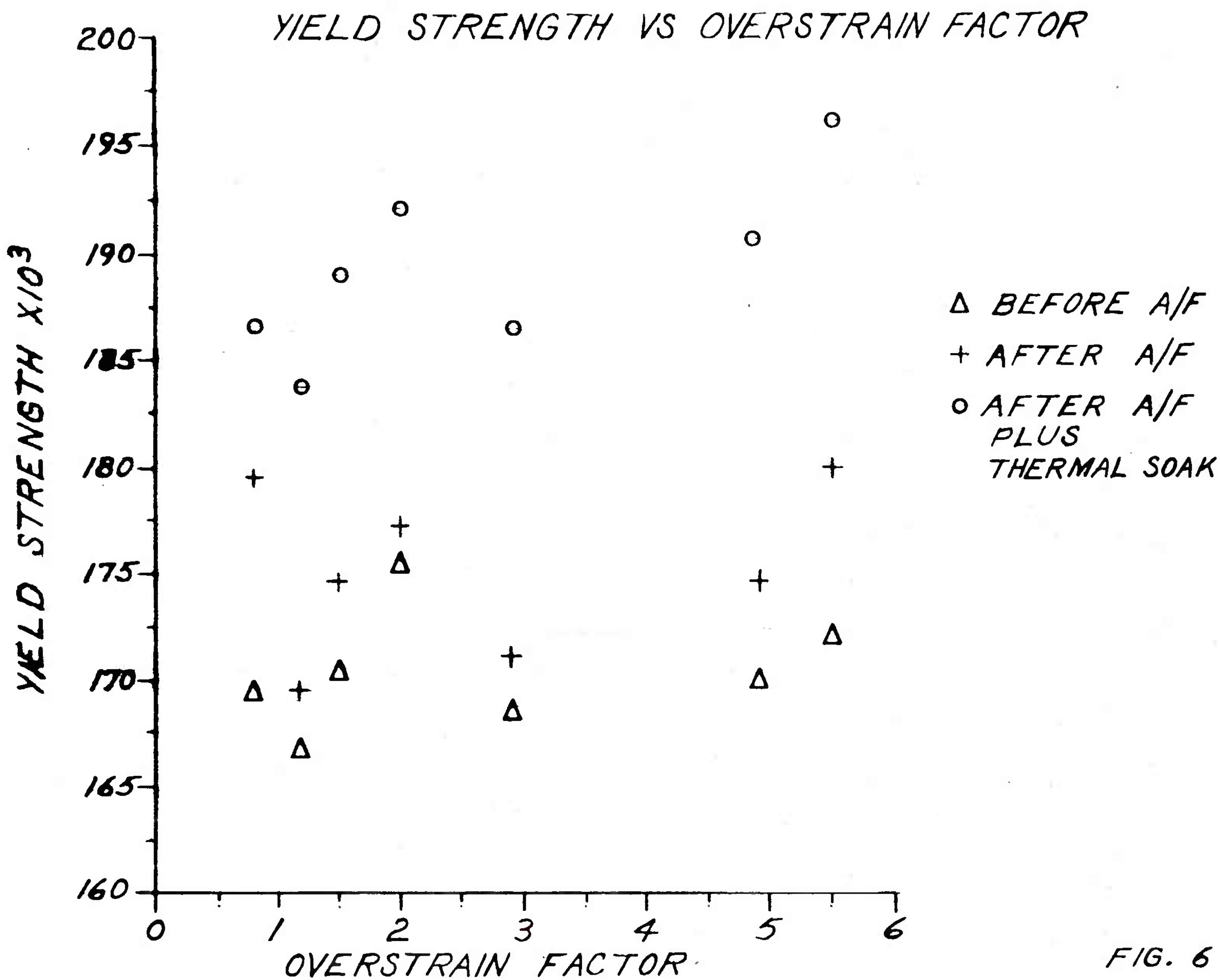


FIG. 5



YIELD STRENGTH VS OVERSTRAIN FACTOR
200
195
190
185
180
175
170
165
160
YIELD STRENGTH X10^3
0
1
2
3
4
5
6
OVERSTRAIN FACTOR
Δ BEFORE A/F
+ AFTER A/F
o AFTER A/F PLUS THERMAL SOAK

FIG. 6

TABLE I

EFFECT OF AUTOFRETTAGE ON CHARPY VALUES - 105MM M68 TUBES

	Pre-Autofrettage		Post-Autofrettage	
Tube #	W/A Avg. -40°F	W/A Avg. 72°F	W/A Avg. -40°F	W/A Avg. 72°F
36	767	1092	628	1031
37	640	1102	554	1032
2	759	1158	578	1027
25	812	1228	745	1036
3	677	1078	558	981
26	703	1198	570	977
62	696	990	638	877
53	760	1070	601	1070
29	717	1224	484	1093
51	704	1052	584	1052
9	808	1283	667	1019
4	615	1109	584	1008

NOTE: W/A average represents five tests per test temperature per tube for both conditions.

W/A = Impact energy per unit area of specimen cross section

TABLE II

CHANGE IN MECHANICAL PROPERTIES AND IMPACT STRENGTH WITH INCREASING OVERSTRAIN

Spec.#	Tube	**Over-Strain Factor	Tensile Strength (ksi) B	Tensile Strength (ksi) A	0.1% Yield Strength (ksi) B	0.1% Yield Strength (ksi) A	% R. A. B	% R. A. A	% El B	% El A	Cv -40 A	Cv R. T. B	Cv R. T. A
	Wall ratio -	1.55											
1	1582MEY4	7.74	186.5	191.5	168	174.8	42.2	38	13.8	12	9.4	24.6	21.5
2	1582BEY9	5.51	189.5	197.4	171.8	179.9	26.1	35.8	10.4	11.4	6.9	15.3	11.6
3	1582BEY5	4.94	186.0	190.4	168.3	173.8	38.9	37.2	12.5	11.5	13.4	24.4	21.9
4	1585ME5	4.85	190.4	195.3	171.5	178	30.9	26.1	11.8	9.9	9.4	16.4	14.2
5	1582BEY6	2.88	186.0	186.6	167.4	170.9	38.9	40.2	13.0	14.2	-	20.1	19.4
6	1582MEY7	2.33	186.1	186.1	167	171.5	30.8	38.9	12.7	13.2	-	21.3	20.5
7	1582BEY8	1.17	184.6	185.8	166.4	168.2	29	39.6	10.2	13.4	12.5	22.3	20.4
8	1585BEY8	1.14	192.0	191.9	171.8	174.9	29.1	38.0	11.1	13.0	9.6	15.9	15.6
	Wall ratio = 2.20												
9	1585BEY7	2.06	193.6	198.8	176.7	176.9	33.4	28.0	11.5	9.2	6.3	14.1	11.3
10	1582BE	1.48	188.8	195.3	170.4	174.2	27.3	24.4	11.6	8.6	10.3	19.2	17.8
11	1585MEY3	.80	194.6	196.5	177.9	177.0	31.5	32.4	11.8	11.5	10.4	14.4	14.2
12	1582BEY2	.79	186.4	196.1	168.2	178.9	39.3	30.2	13.2	11.3	-	14.5	13.9

B = Before A/F

A = After A/F No Thermal Treat

** Overstrain Factor = $\frac{\text{PBE Actual}}{\text{PBE at 100\% overstrain (Calc.)}}$

TABLE III

MECHANICAL PROPERTIES RESULTING FROM
AUTOFRETTAGE AND THERMAL TREATMENT

Spec. #	W = 1.55	Overstrain Factor	*Tensile Strength (ksi)			*0.1% Yield Strength (ksi)			* % R.A.			* % El		
			B	A	T	B	A	T	B	A	T	B	A	T
2	1582BEY9	5.51	189.5	197.4	197	171.8	179.9	196.5	26.1	35.8	34.2	10.4	11.4	11.2
3	1582BEY5	4.94	197.4	190.4	190.7	168.3	173.8	190.5	38.9	37.2	43.6	12.5	11.5	13.3
4	1585ME5	4.85	190.4	195.3	194.8	171.5	178	193.7	30.9	26.1	30.5	11.8	9.9	10.8
5	1582BEY6	2.88	186.0	186.6	187.6	167.4	170.9	186.3	38.9	40.2	37.3	13.0	14.2	12.8
7	1582BEY8	1.17	184.6	185.8	186.2	166.4	168.2	183.6	29.0	39.6	32.2	10.2	13.4	12.7
8	1585BEY8	1.14	192.0	191.9	192.4	171.8	174.9	185.7	29.1	38.0	33.2	11.1	13.0	12.5
	Wall ratio = 2.20													
9	1585BEY7	2.06	190.6	198.8	203.0	175.1	176.9	191.9	33.4	28.0	31.3	11.5	9.2	9.7
10	1582BE	1.48	188.8	193.5	196.2	170.4	174.2	188	27.3	24.4	32.4	11.6	8.6	11
11	1585MEY3	.80	194.6	196.5	200.4	177.9	177.0	192.4	31.5	32.4	26.5	11.8	11.5	10
12	1583BEY2	.79	186.4	196.1	195.6	168.2	178.9	185.8	39.3	30.2	29.3	13.3	11.3	11.5

B = Before Autofrettage
A = After Autofrettage No Thermal Treatment
T = After Thermal Treatment
* = Results are the average of two tests

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NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.